Magnetic Properties of $Pd_{0.996}Mn_{0.004}$ Films for High Resolution Thermometry

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Abstract. We have previously reported on the temperature and magnetic field dependence of the magnetic susceptibility of thin $Pd_{1-x}Mn_x$ alloy films[1]. Extensive new measurements on sputtered films show that a commercial quality sputtering process produces a film with the same dependence of Curie temperature on x as previously reported for bulk samples of the same material[2,3]. These measurements and parameters from the Renormalization Group theory for a Heisenberg ferromagnet[4], yield an estimate for T_c of 1.16 ± 0.01 K when x = 0.004, consistent with previously reported bulk results.

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INTRODUCTION

We reported on the first sputtered alloy films of PdMn using a sputtering target with a concentration of 0.68% (atomic) Mn earlier. We are developing these films for in-situ thermometers intended to measure the temperature profile very near the boundary of a liquid helium cell. This work, when completed, may explain the origin of the singular Kapitza resistance. In this work we lowered the concentration of Mn to 0.4% in an effort to produce films with a T_c below the lambda point of liquid helium. As in the previous effort, films were deposited by DC magnetron sputtering onto substrates of fused silica. The sputtering target was produced by SCI Engineered Materials[5]. Thinfilms, Inc[6], sputtered our substrates to a measured film thickness of 6.7 μm.

DATA COLLECTION

This experiment was conducted in a different cryostat, but using essentially the same technique as the measurements reported in ref. 1. Two samples were mounted 7.5 cm inches from the ends of a 23 cm long niobium flux tube that was 2.5 cm in diameter. This flux tube was mounted on the central axis of the vacuum can and suspended from the lowest of five temperature controlled stages. Each sample was wound with a superconducting pick-up coil that was impedance matched to a Quantum Design DC SQUID mounted on a separate thermally regulated stage within the vacuum cryostat. Temperature control was maintained to within 0.1 mK using a Lake Shore germanium resistance thermometer (GRT) in a Linear Research LR-700 resistance bridge with a built-in feedback heater controller.

Once the temperature of the sample was set and the apparatus was allowed to stabilize the SQUID pickup loop was heated until it went normal to eliminate any persistent currents remaining from the transit between data points. Then the SQUID controller tuning was optimized and a computer was used to collect GRT resistance and SQUID voltage data. After a period of time, a small temperature change, typically <10 mK, would be induced by changing the LR-700 set point and the apparatus was again allowed to stabilize. Transient data was ignored and the steady-state data was used to obtain the local value of the magnetic sensitivity of the PdMn film in units of flux quanta per ohm. The calibration polynomial for the GRT was then used to convert this number into a magnetic sensitivity, (dM/dT), in units of flux quanta per mK. The result for the film mounted with the film surface

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parallel to an applied field of 15 gauss is presented in Figure 1.

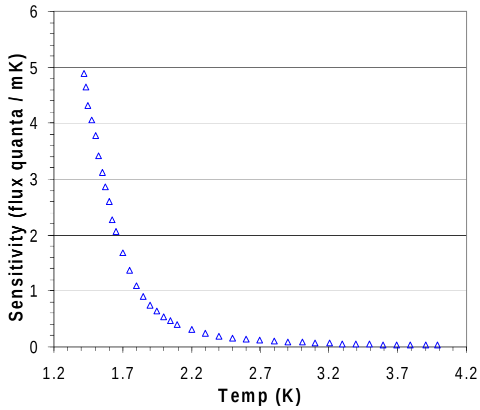

FIGURE 1. Sensitivity of the film sample with the film surface parallel to an applied field of 15 gauss.

RESULTS AND ANALYSIS

As seen in Figure 1, the cryostat was not capable of reaching stable temperatures low enough to observe the ferromagnetic side of this phase transition, so we infer the Curie Temperature, T_c, from the data available and from the form of the divergent magnetic susceptibility χ_T at the Curie temperature. For $T > T_c$,

$$\chi_T = \Gamma\left(\frac{T-T_c}{T_c}\right)^{-\gamma}, \qquad (1)$$

where γ is the critical exponent for the ferromagnetic phase transition and M $=\chi_T$ H, where H is the magnetic field trapped in the Nb flux tube. Making the substitution

$$\left(\frac{dT}{dM}\right)^{\left(\frac{1}{\gamma+1}\right)} = \varsigma \quad , \qquad (2)$$

we obtain

$$\varsigma = \frac{\beta}{T_c}T - \beta \ , \qquad (3)$$

where β is independent of temperature. We fit the data from Figure 1 down to 1.625K (to eliminate the effect of saturation of the sample near the Curie temperature) to this equation. The data is linear with a coefficient of determination of 0.992 and yields an estimate for the Curie temperature of 1.16 K.

To check the validity of this approach and to estimate its absolute uncertainty, we plotted sensitivity vs. reduced temperature, $\tau = \left(\frac{T-T_c}{T_c}\right)$, using values for T_c at intervals of 0.005K. We compared power law fits to these plots, looking for a combination of a high coefficient of determination and an exponent, $-(\gamma+1)$, very close to the theoretical value of -2.4.[4] Analysis of these results yields good fits for values of T_c in the interval $(1.16 \pm 0.01)K$.

We used the lowest field data to estimate T_c, but took data at several values of magnetic field to determine the saturation limits of the sample and to identify a field value where the signal to noise ratio was optimal. The results for magnetic field values ranging from 15 gauss to 105 gauss are presented in Figure 2. This data is presented as a log-log plot in order to separate the data and illustrate the effect of saturation rounding at the lower temperatures.

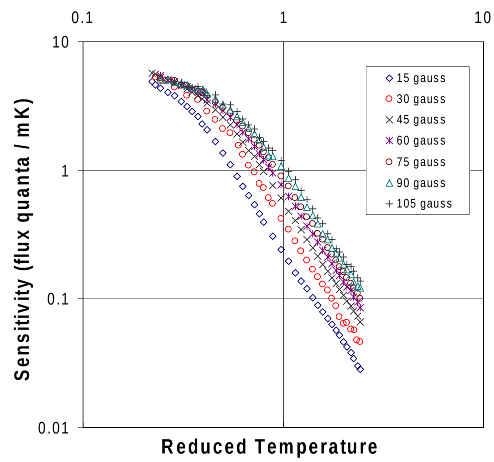

FIGURE 2. Log-log plot of sensitivity vs. τ for several values of magnetic field.

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